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Data Article

Experimental 3D fibre data for tissue papers applications

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ABSTRACT

Tissue paper consumption has been growing for the past years, with a forecasted increase in demand for premium products. Premium tissue paper products are obtained with a balance among softness, strength, and absorption properties, optimized for each kind of tissue paper. These properties are influenced by the three-dimensional structure, made from the spatial distribution of cellulose fibres. To our knowledge, the efforts made to date to improve the softness, strength and absorption properties have overlooked the 3D structure. There is an absence of 3D experimental data in the literature for the simultaneous characterization of individual eucalyptus fibres and the paper structure made from these fibres. The 2D fibre morphology determination, including fibre length and fibre width, was obtained by an image analysis method for pulp fibre suspensions, using the MorFi® equipment. The third fibre dimension, the fibre thickness morphology in the out-of-plane direction, was obtained using SEM images of non-pressed isotropic laboratory-made paper sheets. The effective fibre thickness morphology, consisting of the fibre wall and lumen, was measured in the paper structure, as this is precisely the key fibre parameter, influ-

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encing not only the structure-related properties, such as paper thickness, bulk, and porosity, but also the final end-use properties. The paper structures were produced using an ISO standard adapted method, for tissue paper structures, without pressing, with a basis weight range from 20 to 150 g/m^2. These data are important, among other possible uses, for paper property optimization and simulation studies with 3D fibre based simulators.

Specifications table

Subject	Materials Science (General)
Specific subject area	Tissue Paper Materials
Type of data	Tables and Figures
How data were acquired	MorFi® analyser, SEM analysis, ISO standards methods
Data format	Raw and Analysed
Parameters for data collection	Hardwood isotropic handsheets for different basis weights were obtained using an adaptation of the paper ISO standard (ISO 5269) without the pressing operation, adapted for tissue papers.
Description of data collection	MorFi® analysis was performed to determine the 2D fibre morphology of eucalyptus pulp fibre suspensions. Modified ISO 5269 was used to produce isotropic paper handsheets, dried under tension at 23ªC and 50% humidity (ISO 187). SEM image analysis was performed on paper laboratory-made handsheets to measure the fibre thickness morphology. Paper thickness was measured using paper tissue standard (ISO 12625-3) in a conditioned room (ISO 187). Mass determination was done at 23ªC and 50% humidity (ISO 187).
Data source location	FibEnTech, University of Beira Interior (UBI), Covilhã, Portugal RAIZ- Forest and Paper Research Institute, Eixo, Aveiro, Portugal
Data accessibility	With the article

Value of the Data

- The eucalyptus fibres and the paper structure 3D data are important for paper property optimization and simulation studies with 3D morphology fibre based simulators.
- The data can be used in computational simulation studies to optimize the 3D paper structure-related properties.
- The data is suitable for the calibration process of a computational model for 3D tissue paper [1,2].
- The data is relevant in tissue paper materials research to obtain premium tissue paper materials.

1. Data

A compilation of 3D eucalyptus fibres experimental data, including the 2D fibres morphology characterization (around 15 million fibre per gram), is presented in this article. The 2D eucalyptus fibre morphology is available in Table 1. The key fibre dimension, the effective fibre thickness, was measured using SEM images of eucalyptus paper laboratory-made handsheets, obtained with an adaptation of the ISO standard 5269, without the pressing stage, to better

Table 1
2D fibres morphology analysis of eucalyptus pulp suspension using the fibre analyser MorFi®.

	R1	R2	R3	Mean	Standard deviation
Fibres (million/g)	15.657	15.127	15.191	**15.325**	**0.289**
Length arithmetic (mm)	0.684	0.689	0.687	**0.687**	**0.003**
Length weighted in length (mm)	0.797	0.801	0.799	**0.799**	**0.002**
Width (µm)	18.8	18.8	18.8	**18.8**	**0.0**
Coarseness (mg/m)	0.0938	0.0965	0.0964	**0.0956**	**0.0015**
Kink angle (°)	128	128	128	**128**	**0**
Kinked fibres (%)	37.1	37.2	37.2	**37.2**	**0.1**
Curl (%)	8.6	8.6	8.6	**8.6**	**0.0**
Rate in length of MacroFibrills (%)	0.429	0.426	0.405	**0.420**	**0.013**
Broken Ends (%)	22.33	22.49	22.53	**22.45**	**0.11**
Fine elements (% in length)	43.2	44.9	44.2	**44.1**	**0.9**
Percentage of fine elements (% in area)	16.17	16.52	16.74	**16.48**	**0.29**

R = number of replicates (1, 2 and 3) used to perform the morphological assays

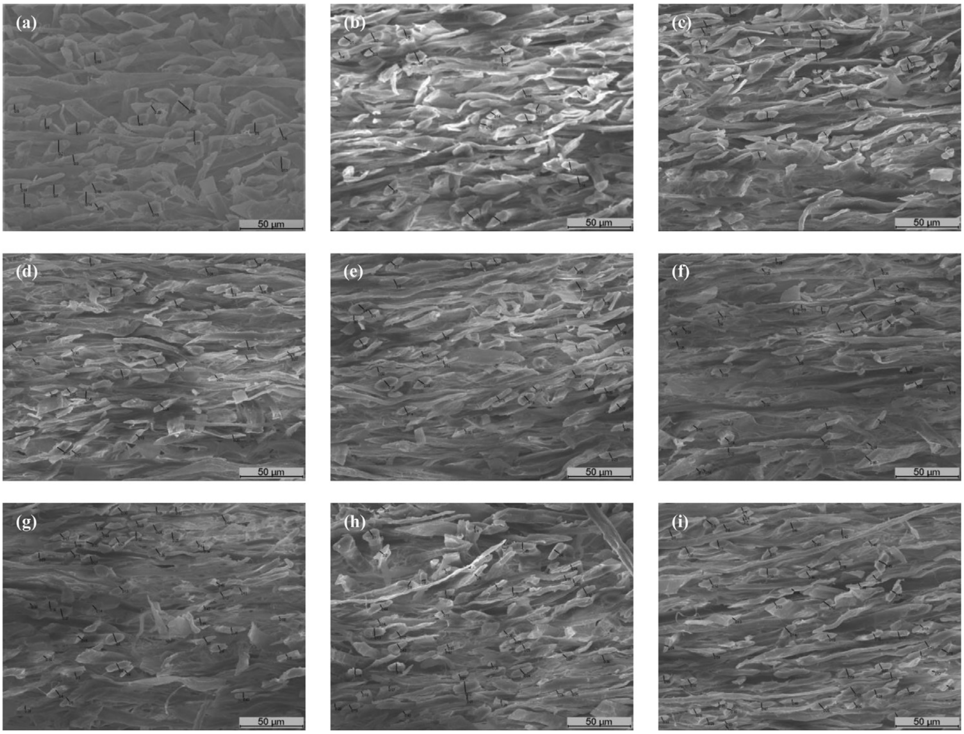

Fig. 1. Out-of-plane handsheets SEM images cross-section (z direction) were taken scanning the paper structure from left to right (x direction) with the same depth (Y direction). Measurements of 322 fibre thicknesses (Table 2) were performed in nine SEM images. The vectors used to measure each fibre thickness are visible in each SEM image. The cross-section (a) represents the measurements of 1–20 fibre' thickness described in Table 2; (b) of 21–41; (c) of 42–73; (d) of 74–103; (e) of 104–138; (f) of 139–174; (g) of 175–219; (h) of 220–264; and (i) of 265–322.

represent tissue paper structure. The fibre thickness measurements, 322 measurements, were performed in nine images (Table 2; Fig. 1). Fig. 1 presents SEM images at different locations in the handsheet cross-section, where the fibre thickness is visible. These measurements were made along the entire handsheet cross-section using the vector placement method. All fibres were identified, numbered and measured, to ensure that each fibre was measured only once,

Table 2
Measurements of the third fibre dimension, the effective fibre thickness in the isotropic handsheet cross-section of the SEM images.

N	Fibre Thickness (µm)	N	Fibre Thickness (µm)	N	Fibre Thickness (µm)
1	1.061	**108**	3.085	**215**	4.278
2	1.186	**109**	3.085	**216**	4.363
3	1.186	**110**	3.085	**217**	4.376
4	1.210	**111**	3.094	**218**	4.414
5	1.210	**112**	3.094	**219**	4.414
6	1.278	**113**	3.094	**220**	4.414
7	1.384	**114**	3.121	**221**	4.458
8	1.424	**115**	3.121	**222**	4.458
9	1.443	**116**	3.121	**223**	4.477
10	1.501	**117**	3.166	**224**	4.477
11	1.661	**118**	3.166	**225**	4.477
12	1.678	**119**	3.192	**226**	4.502
13	1.711	**120**	3.192	**227**	4.509
14	1.853	**121**	3.192	**228**	4.509
15	1.853	**122**	3.228	**229**	4.515
16	1.853	**123**	3.297	**230**	4.515
17	1.898	**124**	3.297	**231**	4.515
18	1.898	**125**	3.305	**232**	4.515
19	1.913	**126**	3.305	**233**	4.534
20	1.913	**127**	3.305	**234**	4.564
21	1.913	**128**	3.356	**235**	4.583
22	1.913	**129**	3.373	**236**	4.583
23	1.913	**130**	3.373	**237**	4.607
24	1.913	**131**	3.398	**238**	4.607
25	2.014	**132**	3.422	**239**	4.662
26	2.014	**133**	3.455	**240**	4.680
27	2.027	**134**	3.455	**241**	4.746
28	2.027	**135**	3.504	**242**	4.746
29	2.027	**136**	3.504	**243**	4.746
30	2.027	**137**	3.504	**244**	4.775
31	2.027	**138**	3.528	**245**	4.775
32	2.041	**139**	3.528	**246**	4.805
33	2.041	**140**	3.528	**247**	4.805
34	2.149	**141**	3.528	**248**	4.869
35	2.239	**142**	3.528	**249**	4.886
36	2.251	**143**	3.559	**250**	4.886
37	2.251	**144**	3.559	**251**	4.892
38	2.337	**145**	3.559	**252**	4.892
39	2.349	**146**	3.559	**253**	4.938
40	2.349	**147**	3.559	**254**	4.955
41	2.373	**148**	3.559	**255**	4.989
42	2.373	**149**	3.559	**256**	4.989
43	2.443	**150**	3.567	**257**	4.989
44	2.443	**151**	3.614	**258**	5.006
45	2.443	**152**	3.614	**259**	5.028
46	2.443	**153**	3.622	**260**	5.034
47	2.443	**154**	3.622	**261**	5.204
48	2.477	**155**	3.622	**262**	5.210
49	2.477	**156**	3.622	**263**	5.221
50	2.477	**157**	3.630	**264**	5.242
51	2.522	**158**	3.630	**265**	5.253
52	2.522	**159**	3.630	**266**	5.269
53	2.522	**160**	3.630	**267**	5.269
54	2.522	**161**	3.684	**268**	5.306
55	2.522	**162**	3.691	**269**	5.354
56	2.556	**163**	3.707	**270**	5.380
57	2.556	**164**	3.707	**271**	5.411

(*continued on next page*)

Table 2 (*continued*)

N	Fibre Thickness (μm)	N	Fibre Thickness (μm)	N	Fibre Thickness (μm)
58	2.556	**165**	3.707	**272**	5.416
59	2.556	**166**	3.707	**273**	5.422
60	2.567	**167**	3.752	**274**	5.463
61	2.567	**168**	3.752	**275**	5.463
62	2.621	**169**	3.797	**276**	5.519
63	2.621	**170**	3.804	**277**	5.540
64	2.621	**171**	3.826	**278**	5.640
65	2.621	**172**	3.826	**279**	5.695
66	2.653	**173**	3.834	**280**	5.700
67	2.653	**174**	3.834	**281**	5.715
68	2.653	**175**	3.863	**282**	5.715
69	2.706	**176**	3.892	**283**	5.715
70	2.706	**177**	3.892	**284**	5.715
71	2.706	**178**	3.892	**285**	5.735
72	2.706	**179**	3.892	**286**	5.774
73	2.706	**180**	3.914	**287**	5.779
74	2.706	**181**	3.949	**288**	5.793
75	2.767	**182**	3.949	**289**	5.837
76	2.767	**183**	3.949	**290**	5.870
77	2.767	**184**	3.949	**291**	5.932
78	2.767	**185**	3.978	**292**	5.932
79	2.767	**186**	3.978	**293**	5.937
80	2.777	**187**	3.978	**294**	5.989
81	2.777	**188**	4.034	**295**	6.050
82	2.848	**189**	4.034	**296**	6.050
83	2.848	**190**	4.034	**297**	6.050
84	2.857	**191**	4.041	**298**	6.064
85	2.857	**192**	4.041	**299**	6.124
86	2.857	**193**	4.041	**300**	6.188
87	2.857	**194**	4.041	**301**	6.211
88	2.857	**195**	4.041	**302**	6.211
89	2.867	**196**	4.041	**303**	6.318
90	2.897	**197**	4.041	**304**	6.367
91	2.897	**198**	4.083	**305**	6.425
92	2.897	**199**	4.083	**306**	6.563
93	2.935	**200**	4.096	**307**	6.649
94	2.935	**201**	4.144	**308**	6.882
95	2.935	**202**	4.151	**309**	6.979
96	2.973	**203**	4.151	**310**	7.356
97	2.973	**204**	4.198	**311**	7.356
98	2.973	**205**	4.198	**312**	7.360
99	3.002	**206**	4.198	**313**	7.582
100	3.002	**207**	4.205	**314**	8.072
101	3.002	**208**	4.245	**315**	8.546
102	3.002	**209**	4.245	**316**	8.546
103	3.020	**210**	4.245	**317**	8.546
104	3.020	**211**	4.271	**318**	8.595
105	3.039	**212**	4.278	**319**	9.255
106	3.039	**213**	4.278	**320**	9.255
107	3.039	**214**	4.278	**321**	9.267
				322	10.939

N = number of fibre measurements using the different SEM images

without repetition. A systematic image analysis methodology approach was developed in order to identify the key features and image analysis criteria to obtain fibre thickness dimensions (wall thickness plus lumen) in the handsheet. An image fraction can only be used if it is representative of the original image. The criterium used to ensure the statistical representativeness is the threshold value for the number of fibres above which the mean value of a property becomes

Table 3
Mass and thickness (tissue ISO 12625–3) of laboratory isotropic handsheets (adaptation of ISO 5629, without pressing) made from Kraft pulp eucalyptus fibres in a conditioned room at 23ªC and 50% humidity (ISO 187) with basis weights in the range of 20–150 g/m^2.

10 handsheets average	Eucalyptus handsheets basis weights (g/m^2)						
	21.1	42.4	63.9	87.0	109.1	129.0	150.9
Mass (g)	0.437	0.911	1.354	1.862	2.323	2.747	3.254
Mass (g)	0.444	0.911	1.369	1.864	2.343	2.764	3.238
Mass (g)	0.456	0.911	1.337	1.870	2.350	2.745	3.242
Mass (g)	0.458	0.912	1.364	1.878	2.344	2.725	3.252
Mass (g)	0.468	0.902	1.370	1.925	2.289	2.730	3.187
Mass (g)	0.452	0.907	1.378	1.880	2.350	2.774	3.172
Mass (g)	0.441	0.883	1.368	1.858	2.339	2.748	3.227
Mass (g)	0.461	1.022	1.376	1.802	2.308	2.756	3.242
Mass (g)	0.465	0.740	1.381	1.841	2.339	2.817	3.227
Mass (g)	0.437	0.968	1.374	1.830	2.347	2.773	3.218
Thickness 1 (µm)	109	175	269	323	422	492	613
Thickness 2 (µm)	104	174	265	309	425	459	544
Thickness 3 (µm)	113	185	257	326	408	474	573
Thickness 4 (µm)	104	185	258	341	409	512	540
Thickness 5 (µm)	113	176	247	315	419	496	593
Thickness 6 (µm)	112	181	238	328	405	475	517
Thickness7 (µm)	107	168	233	312	416	484	566
Thickness 8 (µm)	110	191	239	313	427	474	549
Thickness 9 (µm)	115	157	228	323	427	497	566
Thickness 10 (µm)	111	195	235	322	416	494	568

stable. Mass and thickness of eucalyptus handsheets for different basis weights are presented in Table 3.

Commercial tissue products, such as napkins, toilet papers, towels papers, facial papers, have total paper thicknesses between 50 and 90 µm, for basis weight between 16 and 22 g/m^2 [3]. These materials are usually produced with an arrangement of one to five individual paper sheets (or more), increasing their basis weight and thickness. Therefore, a variety of thickness and basis weight data of isotropic handsheets that mimic tissue papers (without the pressing operation) is considered a highly relevant subject of research.

The analysis of these different 3D fibres data of tissue paper has great relevance, for example, for a computational calibration process of heterogeneous material models, required for the identification of problems and evaluation of possible optimization solutions for these premium papers. The analysis of this data is performed as follows:

1. The morphological properties of the eucalyptus pulp fibres were analysed, using a fibre analyser (MorFi®);
2. The unpressed isotropic handsheets were produced with a basis weights range of 20 to 151 g/m^2, using an adaptation of an ISO standard;
3. The fibre thickness morphology (wall thickness plus lumen) in handsheet cross-section was analysed, using the vector placement method in the SEM images (fibres morphological analysis is essential to promote more real computational representations);
4. The ticknesses (out-of-plane paper dimension) and basis weights of isotropic handsheets were measured, according to a tissue ISO standard (these measurements are essential to understand and quantify the structural changes in the paper).
5. From these data, an analysis of the structures' apparent density can be made, being related to the structures' effective porosity [4].

2. Experimental design, materials and methods

2.1. Pulp samples

A kraft bleached eucalyptus pulp was selected. Laboratory isotropic handsheets were produced from an adaptation of ISO 5269-1 (without the pressing process), to mimic tissue paper materials. A sheet former with a circular shape surface of 0.02138 m^2 was used to made handsheets with different basis weights (between 20 and 151 g m^{-2}) with replicates of 10 times. The samples were conditioned at 23 ± 1°C and 50 ± 2% relative humidity, according to ISO 187.

2.2. Fibres properties analysis

2.2.1. MorFi® analysis

The pulp sample was disintegrated according to ISO 5263. Diluted suspensions of 20 mg L^{-1} was tested using a MorFi® equipment, to obtain the biometric and morphological properties of eucalyptus kraft bleached pulp. This equipment includes a digital camera and 2D image analysis software for the automatic measurement of suspended fibres. The assays were performed in triplicate.

2.2.2. Fibre thickness morphology analysis

The morphology of each effective fibre thickness (wall thickness plus lumen) was evaluated by SEM (Hitachi S2700, with a Bruker detector operating at +20 kV and different magnifications). Previously, the handsheet samples were cuted transversely and placed on an aluminum support with double-side adhesive tape, so that the plane in the handsheet z-direction was analysed. Then, the samples were gold plated using a Sputter Quorum Q 15 OR ES equipment. Throughout this cross-section it was possible to measure 322 fibre thicknesses, using the vector placement method.

2.3. Paper properties analysis

Basis weight or grammage is the mass per unit area (g/m^2) is the structure property of the paper. The paper handsheet thickness was determined using a micrometre (FRANK-PTI GMBH, Birkenau, Germany), according to ISO 1262-3, for tissue paper.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.dib.2020.105479.

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